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PHYSICOCHEMICAL PROCESSES AT THE INTERFACES

The Influence of Liquid on the Deformation Behavior of Human Dentin

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Abstract—The influence of liquid on the mechanical properties of human dentin under uniaxial compression is studied in this work. It has been shown that the storage of samples for 24 h in water, acetone, and glycerin does not lead to a change in the microstructure or to qualitative changes in the mechanical behavior of dentin, which continues to be highly elastic; capable of considerable plastic deformation; and a strong, hard tissue.

Keywords: dentin, liquid, strength.

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INTRODUCTION

It is well known that some environments can dramatically change the deformation behavior of a solid [1]. The influence of the environment is very great for living tissues, inasmuch as biological active liquids play an important role providing the metabolism in an organism. Human dentin, which is the hard basis of a tooth covered by the enamel in crown part and the cement in the root of the tooth, is an example of such a tissue (Fig. 1). Dentin matrix consists of calcium apatite in the ultrafine grained state (crystallite size is 10–50 nm) [2, 3] and of bioorganic connections (collagen fibers) [4, 5]. Concentric dentin tubulars (3–5 μm in diameter) penetrate throughout the entire volume of dentin [6–8] (Fig. 2). Intact dentin is composed of about 25% water, with three-quarters of this (in the form of the dentin liquid) being situated inside the dentin tubulars. There is a pulp chamber filled by soft tissues (nerves and blood vessels) in the central part of the tooth. The strength properties of the tooth decrease after endodontic treatment of a root channel (extraction of pulp), and it should be replaced by an implant. This may be because pulp responses for generation and circulation requires a dental liquid for normal functioning of a tooth.

The strength properties of human dentin have been studied for a long time. However, difficulties caused with preparation of samples for mechanical tests (small sizes and ethical problems) have not allowed unambiguous determination of how this hard tissue behaves under a load [9]. Many researchers consider dentin to be a strong and practically undeformable substance [10]. However, this conclusion contradicts clinical practice and findings concerning indentation [11, 12]. Recently, it has been shown that dry dentin exhibits high elasticity (~15%) and considerable plasticity (~15%) at a high strength (~550 MPà) [13]. Studying the deformation behavior of dentin sustained before tests in various liquids (a physiological solution (0.9% water solution NaCl) to distilled water, spirit colloid solutions (for example, one-malt scotch whisky)) has shown that it can be changed quantitatively, but not qualitatively, under these conditions,

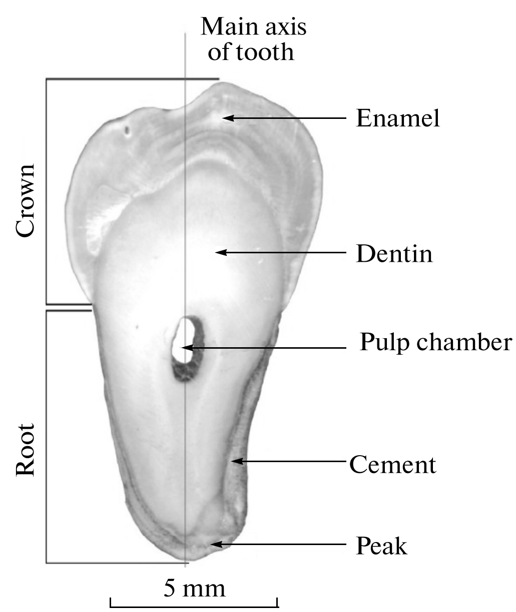

Fig. 1. Composition of mature human tooth (premolar).

[1] The article was translated by the authors.

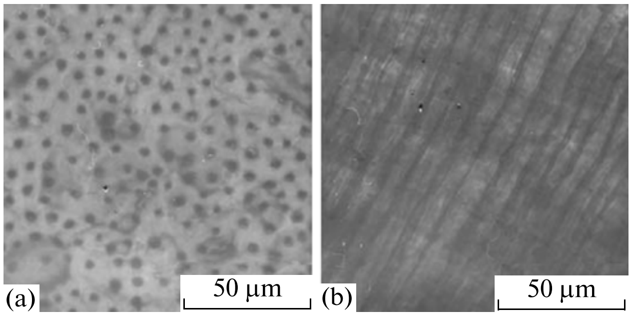

Fig. 2. Microstructure of the dentin matrix: (a) channels oriented normally to surface of image; (b) channels oriented parallel to surface of image.

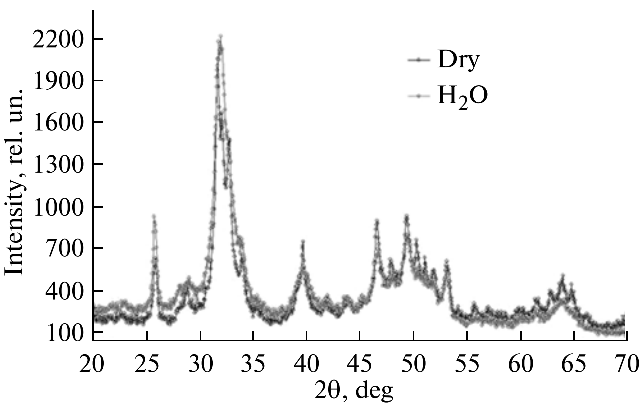

Fig. 3. Diffraction patterns are taken from dry crown dentin samples and those held in water.

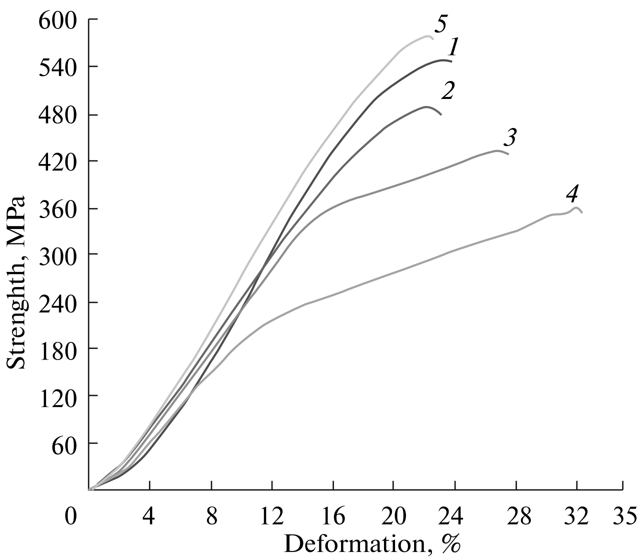

Fig. 4. Deformation curves of dentin samples held for 24 h in (*1*) "dry" dentin, (*2*) aceton, (*3*) *White Horse* whiskey, (*4*) water, and (*5*) glycerin.

with this tissue continuing to be practically undeformable [14, 15]. The aim of this work is to search for the answer to the question of how a liquid can influence the mechanical behavior of human dentin under uniaxial compression.

MATERIALS AND METHODS

Samples for the study of mechanical properties and structure of dentin were cut off from the crown parts of molars and premolars, extracted according to the medical diagnosis, in the form of parallelepipeds with a size of $\sim 2 \times 2 \times 0.65$ mm^3 by the technique described in [13]. To study the influence of a liquid on behavior of dentin under loading, samples were kept in distilled water, acetone, Scotch *White Horse* whiskey, and glycerin for 24 h (on ten pieces for each liquid). Mechanical tests on uniaxial compression were carried out with a help of a Shimadzu AG-X 50kN testing machine (with a rate of traverse of 0.1 mm/min) at room temperature. The size of samples was measured on a UIM-21 instrumental microscope (accuracy ± 1 μm) prior to and after the test. Microstructure of the dentin samples was examined by means of X-ray diffraction on the diffractometer Bruker D8 Advance in Cuk_α-radiation (step 0.05°, scanning time in a point of 10 sec).

RESULTS AND DISCUSSION

Diffraction patterns were taken from samples kept in all the liquids listed above, which were compared with that taken from the dry dentin. Analysis of the diffraction patterns has shown that dentin consists of a single type of calcium apatite that is in ultrafine grained states (with the sizes of crystallites being 10–100 nm) in all cases. This coincides with the finding that there is a dentin microstructure obtained via the method of transmission electron microscopy [13]. Being stored in liquid did not lead to qualitative changes in the diffraction patterns. Therefore, in Fig. 3, data for dry dentin and the sample maintained in H_2O are given. Diffraction peaks in small angles are well resolved from samples maintained in liquid, whereas, in large angles, part of peaks of small intensity is not resolved. This may be connected with the effect of the liquid, both on a surface of the sample and inside the dentin channels.

Mechanical tests are terminated as a jag appears on the deformation curve that corresponds to the occurrence of cracks in the samples, which can be observed by an optical microscope at a magnification of ×20. However, the appearance of cracks did not lead to splitting of the sample into parts, and the compression test could be repeated [13, 16]. The mechanism of crack growth in dentin corresponds with this finding: an extensive plastic zone develops ahead of the main crack tip, where localized accumulation of irreversible deformation takes place and nucleation of porelike

Mechanical properties of dentin samples held in different liquids

	E, GPa	σ_p, MPa	σ_c, MPa	ε_{el}, %	$\varepsilon_{pl.}$, %	ε, %
dry	4.02 ± 0.24	386 ± 21	582 ± 27	14.2 ± 1.0	11.2 ± 1.9	25.5 ± 2.2
aceton	3.83 ± 0.74	363 ± 35	490 ± 42	13.7 ± 2.4	9.5 ± 2.0	23.2 ± 2.6
White Horse whiskey	3.54 ± 0.68	321 ± 27	425 ± 31	12.2 ± 1.8	15.1 ± 2.4	27.3 ± 3.4
water	3.08 ± 0.65	152 ± 38	361 ± 38	8.3 ± 1.9	24.2 ± 3.5	32.5 ± 4.3
glycerin	4.21 ± 0.54	392 ± 41	565 ± 37	14.5 ± 1.8	9.9 ± 2.0	24.3 ± 2.9

cracks occurs [13, 16]. Deformation curves for dentin samples maintained in different liquids are shown on Fig. 4. For comparison, the compression curve of dry dentin is also given. The basic characteristics of their mechanical behavior are presented in the table.

Analysis of the findings has shown that dentin continues to be a highly elastic and strong, hard tissue capable of considerable irreversible deformation after daily storage in a liquid environment. A decrease in the compression strength and elastic deformation, along with an increase in irreversible deformation and full deformation, is observed. The greatest influence on the mechanical properties of dentin is from storage in water, and the least from storage in acetone. This may be connected with the fact that the density of acetone is lower than the density of water and water solutions of alcohol. The similar behavior of dentin under the three-point bend has been described in [14, 15]. The mechanical properties of dentin after retention in glycerin did not differ from the properties of dry dentin. This may be because high-viscosity glycerin does not penetrate into the dentin channels, in contrast with acetone, whisky, and water. Unfortunately, determining if there is liquid in the dentin channels and, if so, how much liquid is situated in the channels and how deeply it has penetrated has not been possible via direct methods. However, if the samples are dried after the first test, then, under repeated compression, they exhibit mechanical properties that are similar to those of dry dentin. This permits it to be suggested that such liquids as water, whisky, and acetone—in contrast with glycerin—penetrate into dentin channels and influence the deformation behavior of human dentin, but do not change its character. In other words, a dentin matrix that contains water or a liquid with lower density in the dentin channels remains highly elastic and a plastic, strong, hard tissue.

It is important for medical science to know how much decreasing the strength properties of dentin described above will be important for the “functional characteristics” of teeth. It is known that, during chewing of normal food, the stress on a tooth does not exceed level 30–50 MPa [17, 18], whereas differences in mechanical properties between dry dentin and dentin that has been soaked in a liquid start to appear only at stresses above 100 MPa. Therefore, the presence of liquid in dentin channels should not affect the mechanical properties of a tooth (assuming, of course, that no attempt is made to bite a steel wire or crack glass), but provides their functioning as a living system.

CONCLUSIONS

On the basis of this research, it may be concluded that the presence of a liquid in the dentin channels does not change the character of the deformation behavior of dentin, which continues to be a highly elastic and strong tissue capable of considerable plastic deformation. The decrease in the mechanical properties of dentin observed at pressure above 100 MPa should not affect the ability of teeth to chew normal human food, because the level of stress in the human mouth does not usually exceed 50 MPa.

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